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An Exposure Model for Identifying Health Risk due to Environmental Microbial Contamination in the Healthcare Setting

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1. Introduction

It is widely accepted in various scientific communities that indoor microbiological contamination presents unacceptable conditions for the preservation of human health, and that removal and prevention of microbial contamination is necessary and prudent. (Pope, Patterson et al. 1993; Macher 1999; EPA 2001; ACOEM 2002; Redd 2002) Additionally, it is well established that fungal and bacterial bioaerosols cause infections and hypersensitivity diseases and that bioaerosols in the indoor environment can cause toxic effects (Karunasena E, Larrañaga MD et al. 2010) and nosocomial infections to immunocompromised individuals, it is reasonable to use indicators of environmental contamination for evaluating the need for remediation in a preventative context. (Macher 1999) The presence of fungi on indoor surfaces is often considered de facto evidence of human exposure to fungal aerosols, and the apparent absence of visible or measurable indoor growth does not ensure the absence of exposure. (Burge 2000) Fungi are designed for airborne dispersal from surface growth, and for many fungi, air movement is sufficient to produce spore aerosols. (Burge 2000) The objective of this chapter is to provide a mechanism for the indoor environmental professional to describe the health risk of the indoor environment with a single unit of measurement, providing decision makers a useful evaluation of the risk presented by the growth of microorganisms indoors.

2. Assessing health risk as a function of environmental contamination

To assess the health risk associated with the environmental microbial contamination within a hospital facility so that administrators could use this information in their decision-making processes, a health risk model (HRM) was utilized based on the text A Strategy for Assessing and Managing Occupational Exposures, Second Edition, a consensus document published by the American Industrial Hygiene Association (AIHA). (Mulhausen and

Damiano 1998) Industrial Hygiene is the science and art devoted to the recognition, evaluation, and control of environmental factors or stresses, arising in or from the work place, which may cause sickness, impaired health and well-being, or significant discomfort and inefficiency among workers or among the citizens of the community. (ABIH 2006)
For the industrial hygienist, exposure assessment and risk assessment are inextricably mixed such that they cannot be separated. Consider the following relationship between health risk and exposure:

Health Risk = (Exposure)(Toxicity [and/or Pathogenicity])

In the world of industrial hygiene, evaluation of exposure is half the assessment of health risk. The other half is evaluation of the health effects per unit exposure, or the toxicity and/or pathogenicity of the agent to which the person is exposed. Any exposure in an industrial hygiene sense is only meaningful in its relationship to the health effects the exposure might cause…The industrial hygienists' ultimate goal is to provide reasonable assurance of occupant health. (Mulhausen and Damiano 1998) In the case of exposure to biological contaminants, toxicity also has a pathogenicity component, as biological contaminants can be pathogenic and/or toxic.
The role of the industrial hygienist is to direct the health assessment so that he or she can make professional judgments on the acceptability of exposure and the associated health risks. The participation of other technical professionals such as engineers, environmental scientists, physicians, toxicologists, safety professionals, etc. is a proven way to streamline the exposure assessment process and improve the quality of assessments. (Mulhausen and Damiano 1998) For the hospital project application of the exposure assessment strategy, an inter-disciplinary team of professionals participated in preparing the model and validating its effectiveness per the interpretations of the investigators and characterization of the overall condition within the facility. Professionals from the following areas participated in the modification, interpretation, and validation of the HRM: medical microbiology, infection control, public health, medicine, engineering, mechanical contracting, medicine, mold assessment consulting, and statistics.
For the HRM, total surface areas for both fungal and bacterial contamination were quantified and sampled to confirm the presence of microbial contamination. Contaminated surfaces were then prescribed a toxicity/pathogenicity score based on the type of microbial contamination identified by sampling. Exposure scores were calculated and multiplied by the toxicity/pathogenicity scores to provide an indication of health risk.

3. Hospital HRM application

The HRM for the hospital project utilized the AIHA Exposure assessment Strategy as a framework for computing health risk. Health Risk is defined as:

Health Risk = (Exposure Score)(Toxicity/Pathogenicity Score)/(Exposure Pathway Score)

In the case of exposure to biological contaminants, toxicity also has a pathogenicity component, as it is well established that bioaerosols can cause infections and hypersensitivity disease and that bioaerosols in the indoor environment may cause toxic effects and nosocomial infections in immunocompromised individuals. Indicators of environmental contamination may be considered for prescribing preventative methods of

control and for making decisions regarding building-related illness and building-related symptoms. (Macher and American Conference of Governmental Industrial Hygienists. 1999)

3.1 Exposure Score (ES) modeling

The ACGIH, EPA, IOM, and CDC recommendations emphasize that active fungal growth in indoor environments is inappropriate and may lead to adverse health effects. The confirmed presence of fungal growth is strong evidence that exposure may occur, and the conditions leading to this should be corrected and the growth removed under appropriate conditions. (Macher and American Conference of Governmental Industrial Hygienists. 1999) This is the premise behind the establishment of increasing levels of protection and containment necessary for remediation of increasing surface areas of contaminated surfaces prescribed by the United States Environmental Protection Agency document "Mold Remediation in Schools and Commercial Buildings" (EPA 2001), the "New York City Guidelines on Assessment and Remediation of Fungi in Indoor Environments" (NYCDHMH 2006), and the ACGIH text Bioaerosols: Assessment and Control. (Macher 1999)

Hence, the Exposure Score modeling is based on the same premise that increasing surface areas of contamination dictate an increased potential of exposure. For a detailed summary of recommendations associated with the above references, see Damp Indoor Spaces and Health published by the Institute of Medicine, 2004. (Institute of Medicine Committee on Damp Indoor Spaces and Health 2004) The ES determination differentiates between critical and non-critical areas within the hospital. Critical areas were defined as the following functional spaces within a hospital: 1) Surgery and Critical Care, 2) Nursing, 3) Ancillary, 4) Diagnostic and Treatment, and 5) Sterilization and Supply; non-critical functional areas were defined as Administration and Service. (ASHRAE 2003) The exposure score, then, is based on the location of exposure, type of procedures conducted in the location, and persons expected to be exposed in those locations.

It is expected that immunocompromised persons, the elderly, newborns, and sick children will be present in the hospital. Protecting children from indoor pollutants is particularly important because 1) children are still developing physically and affected by pollutants to a greater degree than adults, 2) the number of children with asthma has risen approximately 49 percent since 1982, 3) children below the age of 10 have three times as many colds as adults, 4) and children have a higher rate of metabolism than adults and may ingest or inhale more air and surface contaminants than adults (Bayer 2000). Allergic disease (nasal allergy, asthma, and other allergies) is also the number one chronic childhood illness. (Richards 1986) To fully estimate the risk associated with exposure to the immunocompromised and sick children, the HRM was employed by utilizing the maximum score of the tape sample score or the swab sample score and the maximum toxicity/pathogenicity score for each sample in the health risk calculation.

In cases where the exposure pathway was impeded, the exposure score was decreased by one half. The exposure pathway was considered impeded when contamination or growth was identified behind intact vinyl wallpaper or an air handling unit was post-filtered with 90% or 95% final filters, as mandated by the Texas Department of State Health Services. (TDSHS 1994) The exposure score modeling was adapted from the AIHA Exposure Assessment Strategy (Mulhausen and Damiano 1998) to associate increasing amounts of contamination with increased surface area of contamination. Microbial contamination above

the false ceiling was not considered impeded because microbial contamination above ceiling tiles has been shown to move through pores in ceiling tiles and cause nosocomial infections in the space below the false ceilings (Arnow, Andersen et al. 1978) and positive pressure above the false ceilings allows the exchange of air between the space indoors and the space above the false ceilings. See the Assured HVAC report for a detailed description of pressure differentials within the Hospital.

3.1.1 Determination of the exposure score

The exposure score is the maximum of the tape sample and swab sample scores divided by the Exposure Pathway Score:

ES = (MAX[Tape Sample Score, Swab Sample Score])/(Exposure Pathway Score))

Determination of Tape Sample Score:

Tape Sample Score = MAX[Growth Score, Tape Contamination Score]

The information necessary to determine the growth and contamination scores are identified in the Center for Indoor Air Research's Standard Operating Procedures laboratory result sheets for each sample. The laboratory sheets for each sample specify the following: 1) the presence of a fungal growth site for determination of the Growth Score (Table 1), and 2) the laboratory defined level of contamination identified by the tape sample for determination of the Tape Sample Score (Table 2) and 3) the laboratory defined level of contamination identified by the swab sample for determination of the swab sample score. Note: Utilize the maximum value of the scores from Tables 1-2 when determining the Tape Sample Score.
The Growth Score (Table 1) and Tape Contamination Score (Table 2) can be determined by utilizing information presented in the lab sheet for each sample and the estimated surface area of growth or contamination to calculate a value.

3.1.1.1 Determination of the growth score

Table 1 is utilized to determine the Growth Score. If the location is not identified as a growth site, then the growth score is zero.
To determine the Growth Score, multiply the Location Multiplier (values of 1 or 2) by the Growth Multiplier (values of 0 to ≥ 4) found in Table 1. Two Examples are provided:

1. For 35 square feet of fungal growth in a critical area, then the Growth Score is found by multiplying the Location Multiplier which is 2 for a critical area by the Growth Multiplier represented by 35 square feet of growth.
   a. The Location Multiplier for a critical Area is 2 and the Growth Multiplier representing 35 square feet of growth is 2.5. Therefore, the Growth Score would be 2 x 2.5 = 5.
2. For 225 square feet of growth in a non-critical area, the Growth Score is found by multiplying the Location Multiplier which is 1 for a non-critical area and the Growth Multiplier represented by 225 square feet of growth, which would be 4 + 1 (for 100 square feet of additional growth) = 5. Therefore, the Growth Score would be 5 x 1 = 5.

To determine the Tape Contamination Score, multiply the Location Multiplier (values of 1 or 2) by the Tape Multiplier (values of 0 to ≥4) found in Table 2. Two Examples are provided:

3. For 35 square feet of Moderate or Medium Contamination in a critical area, then the Tape Contamination Score is found by multiplying the Location Multiplier which is 2

Location Multiplier	**Growth Score Determination Matrix (Growth Site Identified) (Ranges of Possible Growth Score Values)**				
Critical Area*=2	0	2-3.6	4-5.5	6-7.6	≥ 8
Non-Critical Area**=1	0	1-1.8	2-2.75	3-3.8	≥ 4
Growth Multiplier (determined by amount of contaminated surface area***)	0 (No Growth)	>0-2 ft² = 1 >2-4 ft² = 1.2 >4-6 ft² = 1.4 >6-8 ft² =1.6 >8-10 ft² =1.8	>10-20 ft² =2 >20-30 ft² =2.25 >30-40 ft² =2.5 >40-50 ft² =2.75	>50-60 ft² = 3 >60-70 ft² =3.2 >70-80 ft² =3.4 >80-90 ft² =3.6 >90-100 ft² = 3.8	4 for >100 ft (Add 1 to Growth Multiplier for every additional 100 ft² of contamination)

Note: If a growth site is not identified, then utilize Table 2 to score the matrix.
* A critical area is defined as areas within the following healthcare function spaces: Surgery and Critical Care, Ancillary, Nursing, Diagnostic and Treatment, and Sterilizing and Supply. (ASHRAE 2003)
** A non-critical care area is defined as areas within the following healthcare function spaces: Administration and Service. (ASHRAE 2003)
*** See the following references for protection levels associated with surface areas of contamination: (Macher 1999; EPA 2001; NYCDHMH 2006; VUMC 2006)

Table 1. Fungal Growth Scoring Matrix – Growth Score

Location Multiplier		**Tape Contamination Score Determination Matrix (Ranges of Possible Tape Contamination Score Values)**			
Critical Area*=2		0-5.6	0-7.5	0-7.6	≥ 0
Non-Critical Area**=1		0-2.8	0-3.75	0-3.8	≥ 0
Tape Multiplier (See Lab Contamination Description)	No Growth	0	0	0	0
	Very Light or Few, Light	1	1	1	1
	Moderate or Medium	1	2	2	≥ 3
	Heavy, Very Heavy	2	3	3	≥ 4
Area of Surface Contamination Modifier* (add to Tape Multiplier value)**		>0-2 ft² = add 0 >2-4 ft² = add 0.2 >4-6 ft² = add 0.4 >6-8 ft² = add 0.6 >8-10 ft² = add 0.8	>10-20 ft² = add 0 >20-30 ft² = add 0.25 >30-40 ft² = add 0.5 >40-50 ft² = add 0.75	>50-60 ft² = add 0 >60-70 ft² = add 0.2 >70-80 ft² = add 0.4 >80-90 ft² = add 0.6 >90-100 ft² = add 0.8	>100 ft² (Add 1 to Tape Multiplier for every additional 100 ft² of contamination)

* A critical area is defined as areas within the following healthcare function spaces: Surgery and Critical Care, Ancillary, Nursing, Diagnostic and Treatment, and Sterilizing and Supply. (ASHRAE 2003)
** A non-critical care area is defined as areas within the following healthcare function spaces: Administration and Service. (ASHRAE 2003)
*** See the following references for protection levels associated with surface areas of contamination: (Macher 1999; USEPA 2001; NYCDHMH 2006; VUMC 2006)

Table 2. Fungal Contamination Scoring Matrix – Tape Contamination Score

for a critical area by the Tape Multiplier represented by 35 square feet of Moderate or Medium Contamination is 2 + 0.5 (modifier to account for 35 square feet of contamination) = 2.5.

a. The Location Multiplier for a critical Area is 2 and the Tape Multiplier representing 35 square feet of moderate or medium contamination is 2.5. Therefore, the Tape Contamination Score is 2 x 2.5 = 5.

4. For 225 square feet of moderate or medium contamination in a non-critical area, the Tape Contamination Score is found by multiplying the Location Multiplier which is 1 for a non-critical area and the Tape Multiplier represented by 225 square feet of moderate or medium contamination, which would be 3 + 1 (for 100 square feet of additional contamination) = 4. Therefore, the Tape Contamination Score would be 4 x 1 = 4.

3.1.1.2 Determination of Swab Sample Score (SS): accounts for swab contamination results

The laboratory sheets for each sample specify the laboratory defined level of contamination identified by the swab sample for determination of the swab sample score.
To determine the Swab Sample Score, multiply the Location Multiplier (values of 1 or 2) by the Tape Multiplier (values of 0 to ≥4) found in Table 3.

Location Multiplier		**Swab Sample Score Determination Matrix (bacteria and/or fungi) (Ranges of Possible Swab Sample Score Values)**			
Critical Area*=2		0-5.6	0-7.5	0-7.6	≥ 0
Non-Critical Area**=1		0-2.8	0-3.75	0-3.8	≥ 0
Swab Multiplier (See Laboratory Contamination Description)	No Growth	0	0	0	0
	Very Light or Few	1	1	1	1
	Light or Medium	1	2	2	≥ 3
	Heavy, Very Heavy	2	3	3	≥ 4
Area of Surface Contamination Modifier* (add to Tape Multiplier value)**		>0-2 ft² = add 0 >2-4 ft² = add 0.2 >4-6 ft² = add 0.4 >6-8 ft² = add 0.6 >8-10 ft² = add 0.8	>10-20 ft² = add 0 >20-30 ft² = add 0.25 >30-40 ft² = add 0.5 >40-50 ft² = add 0.75	>50-60 ft² = add 0 >60-70 ft² = add 0.2 >70-80 ft² = add 0.4 >80-90 ft² = add 0.6 >90-100 ft² = add 0.8	>100 ft² Add 1 to Swab Multiplier for every additional 100 ft²

* A critical area is defined as areas within the following healthcare function spaces: Surgery and Critical Care, Ancillary, Nursing, Diagnostic and Treatment, and Sterilizing and Supply. (ASHRAE 2003)

** A non-critical care area is defined as areas within the following healthcare function spaces: Administration and Service. (ASHRAE 2003)

*** See the following references for protection levels associated with surface areas of contamination: (Macher 1999; USEPA 2001; NYCDHMH 2006; VUMC 2006)

Table 3. Microbial Contamination Scoring Matrix – Swab Sample Score

Two Examples are provided:

1. For 35 square feet of Light or Medium Contamination in a critical area, then the Swab Sample Score is found by multiplying the Location Multiplier which is 2 for a critical area by the Swab Multiplier represented by 35 square feet of Light or Medium Contamination is 2 + 0.5 (modifier to account for 35 square feet of contamination) = 2.5.
   a. The Location Multiplier for a critical Area is 2 and the Swab Multiplier representing 35 square feet of light or medium contamination is 2.5. Therefore, the Swab Sample Score is 2 x 2.5 = 5.
2. For 225 square feet of growth in a non-critical area, the Swab Sample Score is found by multiplying the Location Multiplier which is 1 for a non-critical area and the Swab Multiplier represented by 225 square feet of growth, which would be 3 + 1 (for 100 square feet of additional growth) = 4. Therefore, the Swab Contamination Score would be 4 x 1 = 4.

3.2 Exposure Pathway score (EP)

The Health Risk equation was modified to include an Exposure Pathway Score that compensated for microbial contamination or growth that was likely impeded from reaching a building occupant and causing pathogenic effects. See Table 4.

EP	Interpretation
1	Exposure pathway present.
2	Exposure pathway impeded (e.g. contamination is behind in-tact vinyl wallpaper or air is filtered through 90% (or higher) filters prior to entering the space per State of Texas Regulations). (TDSHS 1994)

Table 4. Exposure Pathway Score Scoring Matrix

3.3 Determination of Toxicity/Pathogenicity score (TP)

The literature was reviewed to determine if the organisms identified inside the hospital were associated with pathogenic or opportunistic infections in humans. See Tables 6 and 7 below. Organisms were identified as opportunistic/pathogenic, allergenic, and/or toxigenic if the organism identified was identified as potentially capable of producing a toxin (e.g. aflatoxin, endotoxin, satratoxin). In cases where multiple organisms were identified on a sample, the highest toxicity/pathogenicity score was assigned to the health risk calculation.

TP = sum of individual components: Not Identifiable, Allergenic (A), Toxigenic (T), and/or Opportunistic/Pathogenic based on the organisms identified.

Note: Where multiple organisms are identified on the same sample, the highest Toxicity/Pathogenicity score of the identified organisms is assigned to the calculation.

4. Calculation of health risk score

The Health Risk Score is calculated by multiplying the Exposure Score by the Toxicity/Pathogenicity Score. (Mulhausen and Damiano 1998)

Health Risk = (Exposure Score)(TP Score)

Toxicity/Pathogenicity Identifier	Contamination Score	Interpretation
No Organism Identified	0	No organism was identified.
Not identifiable as A, T, or O/P	1	The organism is not known to be infectious, toxic, or allergenic to humans.
Allergenic (A)	2	The organism has been shown to induce allergy in some individuals (Pope, Patterson et al. 1993; W.B. Saunders 2000)
Toxigenic (T)	2	The organism produces one or more toxins (W.B. Saunders 2000)
Opportunistic/ Pathogenic (FOP) fungi identified	3	The identified organism is either a microorganism that does not ordinarily cause disease but that may cause disease in immunocompromised hosts (opportunistic) and/or any disease producing organism (pathogenic). (W.B. Saunders 2000)
Opportunistic/ Pathogenic (BOP) bacteria identified	3	The identified organism is either a microorganism that does not ordinarily cause disease but that may cause disease in immunocompromised hosts (opportunistic) and/or any disease producing organism (pathogenic). (W.B. Saunders 2000)

Table 5. Determination of Toxicity/Pathogenicity Score

4.1 Health risk scoring interpretation

The criteria for determining the health risk ratings of de minimis, low, medium, and high risk were determined by input from the investigators, peer reviewers, and specialists. Since no guidelines or limits of exposure exist, the expert input was utilized to create estimates of risk based on professional judgment and experience in the fields of medicine, engineering, infection control nursing, industrial hygiene, public health, and medical microbiology. The risk score interpretations and defining criteria are defined as:

de Minimis: No indication of environmental contamination was identified and therefore the risks associated with indoor microbiological contamination are negligible. No remediation is necessary. No further action is warranted. (Spengler, Samet et al. 2001)

Health Risk Score = 0

Low: The environmental conditions present do not indicate extensive biological contamination and/or the risk associated with adverse health affects to building occupants is low. Remediation may be necessary. Containment may be necessary. Remediation may necessitate increased levels of protection (e.g. High Efficiency Particulate Air (HEPA) filtration, full containment). If remediation is warranted, all persons must be removed from the immediate work area, and vacating people from spaces adjacent to the work area is not necessary but is recommended in the presence of infants (less than 12 months old), persons recovering from recent surgery, immune suppressed people, or people with chronic inflammatory lung diseases (e.g., asthma,

hypersensitivity pneumonitis, and severe allergies). (NYCDHMH 2006) Containment may be limited or no containment may be required. See Table 2 of the document Mold Remediation in Schools and Commercial Buildings, the New York Guidelines and Guidelines for Environmental Infection Control in Health-Care Facilities. (EPA 2001; CDC 2003; NYCDHMH 2006)

Defining Criteria: Non-Critical Care Area with <10 square feet of mold growth and heavy or very heavy contamination on either the swab or tape. The Toxicity/Pathogenicity component is equal to Allergenic + Toxigenic, and the exposure pathway is not impeded.

Low Risk Range = 1-11 (rounded down)

Medium: The environmental conditions present an increased risk for adverse health effects to building occupants due to environmental contamination. The indoor environment suggests that immunosuppressed or allergic patients within the hospital are not fully protected against the risk of infection and the allergenic effects due to exposure to environmental-source fungi and bacteria. (Pope, Patterson et al. 1993; Perdelli, Christina et al. 2006) Remediation is necessary. Containment is necessary. Persons within the remediation area must be vacated. Further vacating of people from spaces near the work area is recommended in the presence of infants (less than 12 months old), persons having undergone recent surgery, immune suppressed people, or people with chronic inflammatory lung diseases (e.g., asthma, hypersensitivity pneumonitis, and severe allergies). Containment may be limited or full, with negative air pressure and HEPA filtration exhausted outdoors. Containment may necessitate increased environmental monitoring to establish the effectiveness of containment. See Table 2 of the document Mold Remediation in Schools and Commercial Buildings, the New York Guidelines, and Guidelines for Environmental Infection Control in Health-Care Facilities. (Agency 2001; CDC 2003; NYCDHMH 2006)

Defining Criteria: Non-Critical Care Area, 10-100 square feet of growth with heavy to very heavy contamination on the swab or tape. The Toxicity/Pathogenicity component is equal to Opportunistic/Pathogenic + Toxigenic + Allergenic, and the exposure pathway is not impeded.

Medium Risk Range = >11-26 (rounded down)

High: An indoor environment has been created in which immunosuppressed or allergic patients within the hospital are not fully protected against the risk of infection and the allergenic effects of exposure to environmental-source fungi and bacteria. (Pope, Patterson et al. 1993; Perdelli, Christina et al. 2006) The environmental conditions present a high risk for building occupants and intervention is necessary. The conditions exist for adverse health effects due to exposure to biological contaminants. Remediation is necessary, and during remediation, persons within the remediation area must be vacated. Vacating people from spaces adjacent to the work area is not necessary but is recommended in the presence of infants (less than 12 months old), persons having undergone recent surgery, immune suppressed people, or people with chronic inflammatory lung diseases (e.g., asthma, hypersensitivity pneumonitis, and severe allergies). (NYCDHMH 2006) Full containment is warranted with negative air pressure and HEPA filtration exhausted outdoors. Environmental Monitoring is

warranted to establish the effectiveness of containment. See Table 2 of the document Mold Remediation in Schools and Commercial Buildings, the New York Guidelines, and Guidelines for Environmental Infection Control in Health-Care Facilities. (EPA 2001; CDC 2003; NYCDHMH 2006)

High Risk Range = >26

5. Assumptions and limitations of the determination of the exposure score

Assumptions

The following assumptions were made for the HRM:

1. Increasing surface area of microbial contamination represents an increased potential for exposure to fungal or bacterial environmental contaminants.
2. The maximum surface contamination score (from Tables 1-3) is utilized in determining the Health Risk Score as a marker of exposure.
3. The presence of an impeded exposure does not eliminate the risk associated with biological contamination within the hospital, and therefore, the EP was limited to reducing the exposure score by one-half (Table 4). Environmental disturbances, routine maintenance, climate change, etc. can disturb bioaerosols that may be impeded and release them into the building. (Arnow, Andersen et al. 1978; Loo, Bertrand et al. 1996; Pegues, Daar et al. 2001; CDC 2003) Therefore, a residual risk of exposure remains, even if the exposure is considered impeded.
4. The risk levels are based on the input of experts in related fields to the hospital project. The HRM does not set exposure limits but presents semi-quantitative risk levels based on exposure to microbiological contamination for the estimation of health risk in a hospital setting, where there is no doubt that persons who are ill will be present. There is also no doubt that microbial contamination is present indoors as confirmed by source sampling. See Assured report.

Limitations

The following limitations were identified when applying the HRM to the data:

1. The HRM may underestimate the health risk associated with small areas of growth or contamination in critical areas. For example, the investigators felt that the HR associated with a small amount microbial growth/contamination in a trauma room or surgical suite was significant and presented a high risk. The HRM, however could return a Health Risk Score falling in the low risk range for a small area of fungal growth or heavy contamination in a critical area. The HRM was designed to assess the risk of the entire facility in a broad sense and should not be utilized to assess risk based on one or a few samples. The samples should be of a sufficient number to characterize contaminated surfaces in the space under the control of each air handling unit.
2. The HRM is not sensitive to health risk associated with hidden microbial contamination, as invasive testing was not conducted. A large proportion of contaminated surfaces within buildings may remain hidden and are not visible without invasive investigation. (Dillon, Heinsohn et al. 1996) Therefore, the HRM may underestimate the health risk associated with hidden contamination.
3. The HRM may overestimate the health risk associated with large areas of contamination that are common to most buildings. Specifically, the investigators felt that the

contamination identified in the return air ducts of the HVAC systems was unavoidable and not inconsistent with contamination that could be expected in a return air duct. The investigators felt that the contamination within return air ducts that did not have mold growth did not eliminate the risk associated with contamination, but was not represented by the HRM. Therefore, when calculating the ES for contamination within the return air ducts, the maximum square footage utilized in the calculations was 100 ft^2. After reviewing the values of the HRM associated with the return air ducts, the investigators agreed that the Health Risk Score utilizing a maximum contamination surface area of 100 ft^2 adequately represented the health risk associated with contamination.

4. It is unlikely that adverse conditions and exposure to microbial contamination present within the hospital will affect building occupants equally and there are no exposure limits that would allow the calculation of an uncertainty rating to compare identified conditions with published exposure limits. Dose-response relationships are not available for comparison to environmental levels of indoor bioaerosols. There is no doubt, however that building occupants are being exposed to biological contaminants (allergens, opportunistic pathogens, and biological contaminants that can produce toxic metabolites) that have proliferated on indoor surfaces within the areas of the hospital investigated. The HRM prescribes semi-quantitative estimates of risk based on input from a multi-disciplinary team of professionals whose areas of specialization include microbial contamination in the indoor environment and indoor environmental control. The HRM provides the hospital administration with a method to quantify the risk associated with indoor environmental contamination based on the conditions within the hospital.
5. The HRM does not consider additive or synergistic effects of exposure to multiple organisms and/or toxins/metabolites.
6. The HRM does not represent the indoor conditions of the facility during and immediately after maintenance activities, disruption in electrical service, or the start-up and shut down of the HVAC systems.

6. Conclusion

Allergic reactions to indoor allergens can produce inflammatory diseases of the eyes, nose, throat, and bronchi, which are medical problems that come under the headings of allergic conjunctivitis, allergic rhinitis, allergic asthma, and hypersensitivity pneumonitis (extrinsic allergic alveolitis) respectively. (Pope, Patterson et al. 1993) The Health Risk Model (HRM) considers the type of microbial contamination and the type of person expected to be within a specific Hospital location. Critical care areas are areas of the Hospital where it is expected that immunocompromised persons will be present and therefore contamination within a critical care area is given a higher weight in the overall determination of health risk.

Risk assessment is a process designed to evaluate the potential relationship that may exist between exposure to aeroallergens and a particular effect (e.g. toxic effect, allergic sensitization, infection, allergic disease). (Pope, Patterson et al. 1993) A HRM was utilized to semi-quantitatively identify the health risk associated with fungal and bacterial surface contamination within the hospital. Monitoring for allergens can help characterize environments with respect to specific allergens (e.g., fungi and/or bacteria). Both fungi and bacteria secrete enzymes that act as allergens. (Pope, Patterson et al. 1993) Source or

reservoir samples have been used as indicators of exposure to indoor allergens and measurement interpretations can be semi-quantitative (e.g., "presence or absence" or "low, medium, or high). (Pope, Patterson et al. 1993) Environmental bacteria also grow in all wet spaces and are found in most cases where there is mold growth. (Institute of Medicine Committee on Damp Indoor Spaces and Health 2004)

The American Industrial Hygiene Association's consensus document *A Strategy for Assessing and Managing Occupational Exposures* (Mulhausen and Damiano 1998) served as the basis for the HRM. The HRM utilized criteria and recommendations of the Centers for Disease Control and Prevention (CDC 2003), US Environmental Protection Agency (USEPA 2001), American Conference of Governmental Industrial Hygienists (ACGIH 1999), Institute of Medicine (Pope, Patterson et al. 1993), the New York City Department of Health and Mental Hygiene (NYCDHMH 2006), the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE 2003) and the Vanderbilt University Medical Center (VUMC 2006) in establishing the risk factors for the model. A literature search was conducted to determine if the organisms identified via surface sampling within the hospital were allergenic, pathogenic or opportunistic, and capable of producing fungal or bacterial toxin. The HRM resulted in a Health Risk classification of the space controlled by each AHU.

Health Risk was classified as High, Medium, Low, and de Minimis. The risk classifications were determined with input from experts in medical microbiology, industrial hygiene, public health, engineering controls, infection control, and medicine. A de Minimis risk score means that no indoor environmental contamination was found. A low risk score means the environmental conditions present do not indicate extensive biological contamination and/or the risk associated with adverse health affects to building occupants is low. A medium risk score indicates that environmental conditions present an increased risk for adverse health effects to building occupants due to environmental contamination and remediation is necessary. A high risk score indicates that conditions exist for adverse health effects due to exposure to biological contaminants and immediate intervention is necessary. Figure 9 below displays the HRM scores for the indoor space controlled by each AHU.

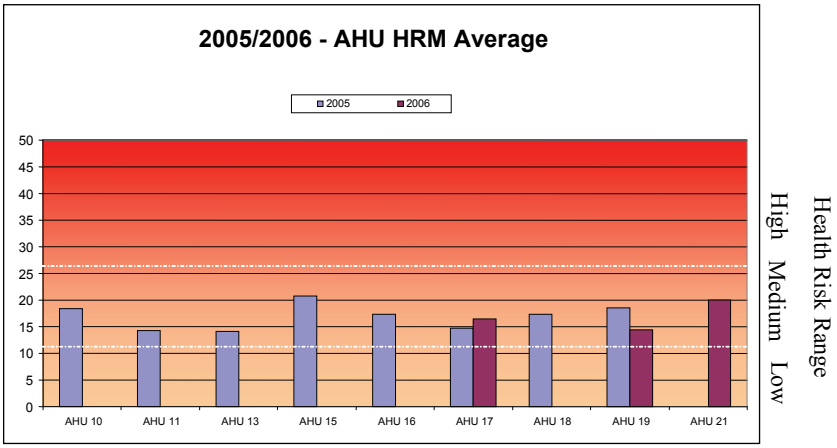

Fig. 9. Health Risk Model Scores for the space controlled by each AHU.

Indoor surface fungal and bacterial surface contamination was identified in every area of the hospital investigated. Air sampling confirmed the presence of indicators of indoor contamination in each of the spaces investigated. See **Section 4. Sampling Interpretation Summary** above. The spaces under the control of every AHU placed within the medium risk category. The environmental conditions are present such that immunocompromised or allergic patients are not fully protected against the risk of NI due to environmental bioaerosols. (Perdelli, Christina et al. 2006) Healthy hospital workers are not protected against allergic reactions to indoor bioaerosols growing within the facility and are at an increased risk of respiratory infections, including the common cold, sinusitis, tonsillitis, otitis, and bronchitis. (Institute of Medicine Committee on Damp Indoor Spaces and Health 2004) Hospital workers who are immunocompromised (e.g., diabetics, asthmatics, those undergoing cancer therapy or who have recent invasive surgery) are more susceptible to allergic reactions and the risk of work-related infections. The results of the HRM indicate that patients and staff are being exposed to microorganisms that are actively growing within the hospital which present a risk higher than what is expected in a hospital without water damage, microbial contamination, moisture infiltration, and OSA infiltration.
Periods of maintenance and non-routine operation of HVAC systems within the hospital can result in filter bypass, dissemination of biological contamination, and the infiltration of unfiltered OSA into the hospital, placing the hospital within the High Risk category due the creation of an exposure pathway during these times. Hence, times during and immediately after maintenance and non-routine operation of the HVAC systems present a high risk for health effects due to bioaerosols in the indoor environment. (CDC 2003)

Organisms Identified (fungal)	**Allergen***	**Opportunistic / Pathogenic***	**Toxin Producer***	**References:**
Absidia species	1	1		(Holzberg and Artis 1983; Gonzalez, del Palacio et al. 1996; Tomsikova 2002; AerotechP&K 2006)
Acremonium species	1	1	1	(Kwon-Chung and Bennett 1992; Macher 1999; Walsh and Groll 1999; Groll and Walsh 2001; Fleming, Walsh et al. 2002; Tomsikova 2002; CDC 2003; Hilmioglu-Polat, Metin et al. 2005; Robles Garcia, Dierssen Sotos et al. 2005; AerotechP&K 2006)
Acrodontium species				
Actinomyces	1	1		(Schaal and Lee 1992; Macher 1999; AerotechP&K 2006)
Actinomycetes	1	1		(Schaal and Lee 1992; Macher 1999; AerotechP&K 2006)
Alternaria sparsus	1	1		(Tomsikova 2002; Ramphal 2006)
Alternaria species	1	1		(Botticher 1966; Aloi, Cervetti et al. 1987; Body, Sabio et al. 1987; Wiest, Wiese et al. 1987; Anaissie, Bodey et al. 1989; Kwon-Chung and Bennett 1992; Niedoszytko,

Organisms Identified (fungal)	Allergen*	Opportunistic / Pathogenic*	Toxin Producer*	References:
				Chelminska et al. 2002; Tomsikova 2002; Wheat, Goldman et al. 2002; Robles Garcia, Dierssen Sotos et al. 2005; AerotechP&K 2006)
Alternaria terreus	1	1		(Venugopal, Venugopal et al. 1989; Hilmioglu-Polat, Metin et al. 2005; AerotechP&K 2006)
Aphanocladium japonicus				
Aphanocladium species				
Arthrinium species	1			(AerotechP&K 2006)
Arthrographis species	1	1		(Degavre, Joujoux et al. 1997; Perlman and Binns 1997; Chin-Hong, Sutton et al. 2001; Biser, Perry et al. 2004; Xi, Fukushima et al. 2004; AerotechP&K 2006)
Ascospores	1	1	1	(AerotechP&K 2006)
Aspergillus alliaceus	1	1	1	(AerotechP&K 2006; Aspergillus.org 2006)
Aspergillus clavato-nanicus	1	1		(AerotechP&K 2006)
Aspergillus clavatus	1	1	1	(Macher 1999; AerotechP&K 2006; Aspergillus.org 2006)
Aspergillus flavipes	1	1	1	(AerotechP&K 2006; Aspergillus.org 2006)
Aspergillus flavus	1	1	1	(Macher 1999; CDC 2003; AerotechP&K 2006; Aspergillus.org 2006; Ramphal 2006)
Aspergillus fumigatus	1	1	1	(Kwon-Chung and Bennett 1992; Macher 1999; AerotechP&K 2006; Aspergillus.org 2006)
Aspergillus japonicus	1	1		(AerotechP&K 2006)
Aspergillus nidulans	1	1	1	(Kwon-Chung and Bennett 1992; Macher 1999; CDC 2003; AerotechP&K 2006; Aspergillus.org 2006)
Aspergillus niger	1	1	1	(Kwon-Chung and Bennett 1992; Macher 1999; CDC 2003; AerotechP&K 2006; Aspergillus.org 2006)
Aspergillus niveus	1	1		(AerotechP&K 2006)
Aspergillus oryzae	1	1	1	(Kwon-Chung and Bennett 1992; AerotechP&K 2006; Aspergillus.org 2006)
Aspergillus parasiticus	1		1	(Macher 1999; AerotechP&K 2006; Aspergillus.org 2006)
Aspergillus sclerotiorum	1		1	(AerotechP&K 2006; Aspergillus.org 2006)

Organisms Identified (fungal)	Allergen*	Opportunistic / Pathogenic*	Toxin Producer*	References:
Aspergillus sojae	1			(AerotechP&K 2006)
Aspergillus sydowii	1	1		(AerotechP&K 2006)
Aspergillus terreus	1	1	1	(Kwon-Chung and Bennett 1992; CDC 2003; AerotechP&K 2006; Aspergillus.org 2006)
Aspergillus ustus	1	1	1	(Kwon-Chung and Bennett 1992; AerotechP&K 2006; Aspergillus.org 2006)
Aspergillus versicolor	1	1	1	(Kwon-Chung and Bennett 1992; Macher 1999; AerotechP&K 2006; Aspergillus.org 2006)
Aureobasidium species		1		(Venugopal, Venugopal et al. 1989; Trupl, Minarik et al. 1995; Huttova, Kralinsky et al. 1998; Tomsikova 2002)
Basidiomycetes		1		(Bartz-Schmidt, Tintelnot et al. 1996; Nenoff, Horn et al. 1996; Rihs, Padhye et al. 1996; Nenoff, Friedrich et al. 1997; Sigler, Estrada et al. 1997; Verweij, van Kasteren et al. 1997)
Basidiospores	1			(AerotechP&K 2006)
Beauveria species	1			(AerotechP&K 2006)
Bipolaris species	1	1	1	(Rao, Forgan-Smith et al. 1989; Walsh, Gonzalez et al. 1995; Walsh and Groll 1999; Groll and Walsh 2001; Fleming, Walsh et al. 2002; Tomsikova 2002; Robb, Malouf et al. 2003; AerotechP&K 2006; Toul, Castillo et al. 2006)
Chaetomium species	1	1	1	(Kwon-Chung and Bennett 1992; Naidu 1993; Tomsikova 2002; AerotechP&K 2006)
Chrysosporium species	1	1	1	(Kwon-Chung and Bennett 1992; AerotechP&K 2006)
Circinella species				
Cladosporium cladosporioides	1	1		(Kwon-Chung and Bennett 1992; AerotechP&K 2006)
Cladosporium herbarum	1	1		(AerotechP&K 2006)
Cladosporium-like	1	1		(AerotechP&K 2006)
Cladosporium macrocarpum	1	1		(AerotechP&K 2006)
Cladosporium oxysporum	1	1		(AerotechP&K 2006)
Cladosporium species	1	1		(CDC 2003; AerotechP&K 2006)
Cladosporium sphaerospermum	1			(AerotechP&K 2006)
Coelomycetes species				
Corynespora species				(AerotechP&K 2006)
Curvularia species	1	1		(Loveless, Winn et al. 1981; Anaissie, Bodey et al. 1989; Venugopal, Venugopal et al. 1989; Naidu 1993; AerotechP&K 2006)

Organisms Identified (fungal)	Allergen*	Opportunistic / Pathogenic*	Toxin Producer*	References:
Emericella nidulans		1	1	(AerotechP&K 2006)
Engyodontium species		1		(Abarca 2000)
Epicoccum species	1	1		(AerotechP&K 2006)
Eupenicillium species				
Exophiala species	1	1	1	(AerotechP&K 2006)
Exserohilum species	1	1		(Tomsikova 2002)
Fonsecaea species	1	1		
Fusarium species	1	1	1	[3-12, 16, 20, 28, 45-47]
Geotrichum species	1	1		(AerotechP&K 2006)
Gliocladium species	1			(AerotechP&K 2006)
Hormographiella species		1		(Verweij, van Kasteren et al. 1997; AerotechP&K 2006)
Malbranchea species		1		
Mucor species	1	1		(Mikat 1980; Holzberg and Artis 1983; Fotedar and Banerjee 1992; Kwon-Chung and Bennett 1992; Gonzalez, del Palacio et al. 1996; Muhm, Zuckermann et al. 1996; AerotechP&K 2006)
Myxomycetes	1			(AerotechP&K 2006)
Nigrospora species	1			(AerotechP&K 2006)
Ochroconis species		1		(Tomsikova 2002)
Paecilomyces marquandii	1	1		(Kwon-Chung and Bennett 1992; Naldi, Lovati et al. 2000; AerotechP&K 2006)
Paecilomyces species	1	1		(Kwon-Chung and Bennett 1992; Walsh and Groll 1999; Naldi, Lovati et al. 2000; Groll and Walsh 2001; Fleming, Walsh et al. 2002; Tomsikova 2002; AerotechP&K 2006)
Paecilomyces variabile	1	1		(AerotechP&K 2006)
Paecilomyces variotii	1	1		(Akhunova and Shustova 1989; Akhunova 1991; Naidu 1993; Dhindsa, Naidu et al. 1995; Young, Hertl et al. 1995; Athar, Sekhon et al. 1996; AerotechP&K 2006)
Penicillium/Aspergillus-like	1			(AerotechP&K 2006)
Penicillium aurantiogriseum	1		1	(Frisvad and Filtenborg 1983; Yeulet, Mantle et al. 1988; AerotechP&K 2006)
Penicillium brevicaulis	1			(AerotechP&K 2006)
Penicillium brevicompactum	1	1	1	(Frisvad and Filtenborg 1983; AerotechP&K 2006)
Penicillium chrysogenum	1	1	1	(Frisvad and Filtenborg 1983; Kwon-Chung and Bennett 1992; Macher 1999; Lyratzopoulos, Ellis et al. 2002; AerotechP&K 2006)

Organisms Identified (fungal)	Allergen*	Opportunistic / Pathogenic*	Toxin Producer*	References:
Penicillium citrinum	1		1	(Vujanovic, Smoragiewicz et al. 2001; AerotechP&K 2006)
Penicillium commune	1			(AerotechP&K 2006)
Penicillium corylophilum	1			(AerotechP&K 2006)
Penicillium decumbens	1	1		(Kwon-Chung and Bennett 1992; Lyratzopoulos, Ellis et al. 2002; AerotechP&K 2006)
Penicillium duclauxii	1			(AerotechP&K 2006)
Penicillium fellutanum	1			(AerotechP&K 2006)
Penicillium funiculosum	1			(AerotechP&K 2006)
Penicillin griseofulvum	1		1	(Macher 1999; AerotechP&K 2006)
Penicillium implicatum	1			(AerotechP&K 2006)
Penicillium janthinellum	1			(AerotechP&K 2006)
Penicillium miczynskii	1			(AerotechP&K 2006)
Penicillium minioluteum	1			(AerotechP&K 2006)
Penicillium oxalicum	1		1	(Macher 1999; AerotechP&K 2006)
Penicillium oxysporum	1			(AerotechP&K 2006)
Penicillium pinophilum	1			(AerotechP&K 2006)
Penicillium purpurogenum	1	1		(Breton, Germaud et al. 1998; AerotechP&K 2006)
Penicillium rugulosa	1			(AerotechP&K 2006)
Penicillium sclerotiorum	1			(AerotechP&K 2006)
Penicillium simplicissimum	1			(AerotechP&K 2006)
Penicillium species	1	1	1	(Frisvad and Filtenborg 1983; Streifel, Stevens et al. 1987; Yeulet, Mantle et al. 1988; Fox, Chamberlin et al. 1990; Chakrabarti, Nayak et al. 1992; Gaye, Samb et al. 1992; Kwon-Chung and Bennett 1992; Walsh and Groll 1999; Lyratzopoulos, Ellis et al. 2002; CDC 2003; Robles Garcia, Dierssen Sotos et al. 2005; AerotechP&K 2006)
Penicillium thomii	1			(AerotechP&K 2006)
Penicillium variabile	1			(AerotechP&K 2006)
Penicillium waksmanii	1			(AerotechP&K 2006)
Periconia species				(AerotechP&K 2006)
Peronospora species				(AerotechP&K 2006)
Pithomyces species			1	(Macher 1999; AerotechP&K 2006)
Ramichloridium species		1		(Naim ur, Mahgoub et al. 1988; Jamjoom, al-Hedaithy et al. 1995; Sutton, Slifkin et al. 1998; Podnos, Anastasio et al. 1999; De Hoog, Queiroz-Telles et al. 2000; Kanj, Amr et al. 2001; Brandt and

Organisms Identified (fungal)	Allergen*	Opportunistic / Pathogenic*	Toxin Producer*	References:
				Warnock 2003; Kantarcioglu and de Hoog 2004; Al-Abdely, Alkhunaizi et al. 2005)
Rhizomucor species	1	1		(del Palacio Hernanz, Fereres et al. 1983; Severo, Job et al. 1991; Gonzalez, del Palacio et al. 1996; AerotechP&K 2006)
Rhizopus species	1	1		[1-4, 11, 49, 75-84]
Rhizopus oryzae	1	1		(Bottone, Weitzman et al. 1979; Telles Filho Fde, Coelho et al. 1985; Kwon-Chung and Bennett 1992; Gonzalez, del Palacio et al. 1996; Muhm, Zuckermann et al. 1996; Linder, Keller et al. 1998; AerotechP&K 2006; Lai, Liaw et al. 2006)
Rhodotorula species		1		(Walsh, Gonzalez et al. 1995; Huttova, Kralinsky et al. 1998; Costa, Marinho et al. 2000; Groll and Walsh 2001; Tomsikova 2002; Centeno and Machado 2004; AerotechP&K 2006)
Scedosporium species		1		[3-6, 11, 34, 60, 65, 87-90]
Scytalidium species		1		(Summerbell, Kane et al. 1989; Gaye, Samb et al. 1992; Brandt and Warnock 2003; AerotechP&K 2006)
Stachybotrys species	1		1	(Sudakin 1998; AerotechP&K 2006; Solomon, Hjelmroos-Koski et al. 2006)
Stemphylium species	1	1		(AerotechP&K 2006)
Sterile mycelia	1			(AerotechP&K 2006)
Syncephalastrum racemosus	1	1		(AerotechP&K 2006)
Tetraploa species				(AerotechP&K 2006)
Torula species	1			(Walsh, Gonzalez et al. 1995; Huttova, Kralinsky et al. 1998; Costa, Marinho et al. 2000; Groll and Walsh 2001; Tomsikova 2002; Centeno and Machado 2004; AerotechP&K 2006)
Trichoderma species	1	1	1	(Guarro, Antolin-Ayala et al. 1999; Richter, Cormican et al. 1999; Walsh and Groll 1999; Fleming, Walsh et al. 2002; Myoken, Sugata et al. 2002; Kredics, Antal et al. 2003; De Miguel, Gomez et al. 2005; Hilmioglu-Polat, Metin et al. 2005; AerotechP&K 2006)

Organisms Identified (fungal)	Allergen*	Opportunistic / Pathogenic*	Toxin Producer*	References:
Trichoderma viride	1	1	1	(Kwon-Chung and Bennett 1992; De Miguel, Gomez et al. 2005; AerotechP&K 2006)
Tritirachium species		1		(Rodrigues and Laibson 1975; AerotechP&K 2006)
Ulocladium species	1	1		(Gaye, Samb et al. 1992; Duran, Del Pozo et al. 2003; Hilmioglu-Polat, Metin et al. 2005; AerotechP&K 2006)
Verticillium species		1		(Amici, Grandesso et al. 1994; Shin, Kim et al. 2002; AerotechP&K 2006)
yeast		1		(AerotechP&K 2006; Ramphal 2006)

*A 1 signifies that the organism is opportunistic or pathogenic and or capable of producing a toxin.

Table 6. Pathogenicity and Toxicity Potential of Fungal Organisms

Organisms Identified (Bacteria)	Pathogenicity*	Toxin Producer (endotoxin)*	References
Acinetobacter lwoffi	1	1	(Crawford, Conway et al. 1997; Rathinavelu, Zavros et al. 2003; Larson, Cimiotti et al. 2005; Mathews, Mathews et al. 2005)
Acinetobacter species	1	1	(Bergogne-Berezin 2001; Alvarez-Lerma, Palomar et al. 2005; Benitez and Ricart 2005; Agodi, Zarrilli et al. 2006)
Actinomycetes	1		(Schaal and Lee 1992)
Aerococcus viridans			
Aeromonas hydrophila (Cheng, Horng et al. 2004)	1		(NNISR 1979; Poirier, Laurens et al. 1993; Davin-Regli, Bollet et al. 1998; Cheng, Horng et al. 2004)
Bacillus species	1		(Richard, Van der Auwera et al. 1988; Matsumoto, Suenaga et al. 2000; Yang, Xu et al. 2000; Newman 2002)
Bordetella bronchiseptica	1	1	(Bizet and Bizet 1995; Stevens-Krebbers, Schouten et al. 1999; Huebner, Christman et al. 2006)
Burkholderia cepacia	1	1	(Jang, Kuo et al. 1999; Belchis, Simpson et al. 2000; Matrician, Ange et al. 2000; Bureau-Chalot, Piednoir et al. 2003; Shehabi, Abu-Al-Soud et al. 2004; Balkhy, Cunningham et al. 2005; Berthelot, Grattard et al. 2005)

Organisms Identified (Bacteria)	Pathogenicity*	Toxin Producer (endotoxin)*	References
Burkholderia gladioli	1	1	(Wilsher, Kolbe et al. 1997; Otterbein, Splettstoesser et al. 1998; Clode, Metherell et al. 1999; Segonds, Heulin et al. 1999; Segonds and Chabanon 2001)
Burkholderia species	1	1	(Otterbein, Splettstoesser et al. 1998; Segonds, Heulin et al. 1999; Segonds and Chabanon 2001)
Chryseomonas luteola	1		(Hawkins, Moriarty et al. 1991; Ndugulile, Jureen et al. 2005)
Citrobacter freundii	1		(Hodges, Degener et al. 1978; Tejada Artigas, Bello Dronda et al. 2001; Fiorio, Marroni et al. 2004; Ndugulile, Jureen et al. 2005)
Comamonas acidovrans			
Diptheroids	1		(Schofferman, Zucherman et al. 1991)
Enterobacter agglomerans	1		(Geere 1977; Goldmann, Dixon et al. 1978; Maki 1981; Astagneau, Gottot et al. 1994)
Escherichia coli	1	1	(Hoogkamp-Korstanje, Cats et al. 1982; Raymond 2000; Newman 2002; Larson, Cimiotti et al. 2005; Kramer, Schwebke et al. 2006; Toniolo, Endimiani et al. 2006)
Flavimonas oryzihabitans	1	1	(Hawkins, Moriarty et al. 1991)
Flavobacterium meningosepticum	1	1	(Abrahamsen, Finne et al. 1989; Liu, Wong et al. 1999; Bellais, Girlich et al. 2002; Seetha, Bairy et al. 2002)
Flavobacterium breve	1	1	(Bellais, Girlich et al. 2002)
Gram (+) cocci	1		(Peter, Jehl et al. 1988; Rosina 1991; Zhang 1991; Pechere 1993; Astagneau 1998; Gayvallet-Montredon, Sauvestre et al. 1998; Raymond 2000)
Gram (+) cocci in clumps	1		(Peter, Jehl et al. 1988; Rosina 1991; Zhang 1991; Pechere 1993; Astagneau 1998; Gayvallet-Montredon, Sauvestre et al. 1998; Raymond 2000)
Gram (-) cocci	1		(Berk and Verghese 1989; Donowitz 1989; Zhang 1991;

Organisms Identified (Bacteria)	Pathogenicity*	Toxin Producer (endotoxin)*	References
			Carlisle, Gucalp et al. 1993; Pechere 1993; Du, Chen et al. 1996; Astagneau 1998; Gayvallet-Montredon, Sauvestre et al. 1998; McEachern and Campbell 1998; Jones, Low et al. 1999; Lang, Livesley et al. 1999; Karchmer 2000; Raymond 2000; Raymond and Aujard 2000; Chang, Carvalho et al. 2003; Palabiyikoglu, Tekeli et al. 2006)
Gram Negative Rod Non-Fer	1	1	(Berthelot, Grattard et al. 2005)
Gram Negative Rods	1	1	(LaForce 1981; Carlisle, Gucalp et al. 1993; Pechere 1993; McEachern and Campbell 1998; Berthelot, Grattard et al. 2005; Toniolo, Endimiani et al. 2006)
Micrococcus luteus	1		(Marinella, Pierson et al. 1997)
Micrococcus sp.	1		(Meyer, Eitzen et al. 1981; Hughes, Williams et al. 1986; Marinella, Pierson et al. 1997; Davies, Mehr et al. 2000)
Micrococcus species	1		(Meyer, Eitzen et al. 1981; Hughes, Williams et al. 1986; Marinella, Pierson et al. 1997; Davies, Mehr et al. 2000)
Myroides odoratum	1	1	(Mammeri, Bellais et al. 2002)
Nocardia sp.	1		(Simpson, Stinson et al. 1981; Schaal and Lee 1992)
Nocardioform	1		(Poonwan, Kusum et al. 1995; Votava, Skalka et al. 1997)
Nocardioform bacilli	1		(Poonwan, Kusum et al. 1995; Votava, Skalka et al. 1997)
Nocardioform bacilli Cog.	1		(Poonwan, Kusum et al. 1995; Votava, Skalka et al. 1997)
Presumptive *Nocardioform*	1		(Poonwan, Kusum et al. 1995; Votava, Skalka et al. 1997)
Pseudomonas aeruginosa	1	1	(Hoogkamp-Korstanje, Cats et al. 1982; Celis, Torres et al. 1988; Zhang 1991; Du, Chen et al. 1996; Hijazi and MacIntyre 2000; Yang, Xu et al. 2000; Esen and Leblebicioglu 2004; Fiorio, Marroni et al. 2004; Berthelot, Grattard et al. 2005; Branger 2005; Crnich, Safdar et al. 2005; Wang, Chang et al. 2005; Toniolo, Endimiani et al. 2006)

Organisms Identified (Bacteria)	Pathogenicity*	Toxin Producer (endotoxin)*	References
Pseudomonas diminuta	1	1	(Forbes, Sahm et al. 1998)
Pseudomonas fluorescens	1	1	(Franzetti, Cernuschi et al. 1992; Burgos, Torres et al. 1996; Forbes, Sahm et al. 1998; Hsueh, Teng et al. 1998; Forbes, Sahm et al. 2002)
Pseudomonas orizihabitans		1	
Pseudomonas stutzeri	1	1	(Forbes, Sahm et al. 1998)
Ralstonia picketti	1	1	(Adiloglu, Ayata et al. 2004)
Rhizobium radiobacter	1	1	(Potvliege, Vanhuynegem et al. 1989; Lai, Teng et al. 2004)
Sphingomonas paucimobilis	1	1	(de Otero, Masip et al. 1998; Hsueh, Teng et al. 1998; Perola, Nousiainen et al. 2002)
Staphylococcus aureus	1	1	(McGowan 1988; Berk and Verghese 1989; Peters 1991; Astagneau 1998; Barie 1998; Raymond 2000; Yang, Xu et al. 2000; Fiorio, Marroni et al. 2004; Branger 2005; Lee, Hua et al. 2005; Jerassy, Yinnon et al. 2006; Toniolo, Endimiani et al. 2006)
Staphylococcus auricularis			
Staphylococcus capitis	1		(Wang, Liu et al. 1999; Van Der Zwet, Debets-Ossenkopp et al. 2002)
Staphylococcus cohnii	1		(Narayani, Naseema et al. 1990; Szewczyk, Piotrowski et al. 2000)
Staphylococcus capitos			
Staphylococcus cohnii			
Staphylococcus epidermis	1		(Peters 1991; Perez Monras, Azahares Romero et al. 1992; Branger 2005; Larson and Dinulos 2005)
Staphylococcus hominis	1		(Ponce de Leon, Guenthner et al. 1986; Narayani, Naseema et al. 1990; Lang, Livesley et al. 1999; Szewczyk, Piotrowski et al. 2000; Basaglia, Moras et al. 2003)
Staphylococcus hyicus			
Staphylococcus haemolyticus	1		(Ponce de Leon, Guenthner et al. 1986; Narayani, Naseema et al. 1990)
Staphylococcus hominis	1		(Ponce de Leon, Guenthner et al. 1986; Narayani, Naseema et

Organisms Identified (Bacteria)	Pathogenicity*	Toxin Producer (endotoxin)*	References
			al. 1990; Lang, Livesley et al. 1999; Szewczyk, Piotrowski et al. 2000)
Staphylococcus salvarius			
Staphylococcus saprophyticus	1		(Hoogkamp-Korstanje, Cats et al. 1982; Cohen 1986; Narayani, Naseema et al. 1990; Hell, Kern et al. 1999; Lang, Livesley et al. 1999; Szewczyk, Piotrowski et al. 2000; von Eiff, Proctor et al. 2001; von Eiff, Peters et al. 2002)
Staphylococcus sciuri	1		(Lang, Livesley et al. 1999; Stepanovic, Dakic et al. 2002)
Staphylococcus sp. coag neg	1		(Maki 1981)
Staphylococcus warneri	1		(Ponce de Leon, Guenthner et al. 1986; Buttery, Easton et al. 1997)
Staphylococcus xylosus	1		(Narayani, Naseema et al. 1990; Won, Kwon et al. 2002)
Staphylococcus sp. Cog.	1		(Maki 1981)
Stenotroph maltophilia	1		(Berthelot, Grattard et al. 2005)
Suggestive *Diptheroids*			
Tatumella ptyseos	1		(Hollis, Hickman et al. 1981)

*A 1 signifies that the organism is opportunistic or pathogenic and/or gram negative.

Table 7. Pathogenicity and Toxicity Potential of Bacterial Organisms

7. References

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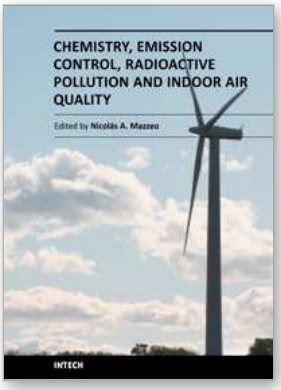

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The atmosphere may be our most precious resource. Accordingly, the balance between its use and protection is a high priority for our civilization. While many of us would consider air pollution to be an issue that the modern world has resolved to a greater extent, it still appears to have considerable influence on the global environment. In many countries with ambitious economic growth targets the acceptable levels of air pollution have been transgressed. Serious respiratory disease related problems have been identified with both indoor and outdoor pollution throughout the world. The 25 chapters of this book deal with several air pollution issues grouped into the following sections: a) air pollution chemistry; b) air pollutant emission control; c) radioactive pollution and d) indoor air quality.

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